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SPECTROMETER FOR ATMOSPHERIC IONS IN THEIR UPPERMOST RANGE OF MOBILITY

(Project: Measuring Ionic Mobilities in the Terrestrial Upper Stratosphere and Mesosphere--Phase II)

Prepared by

AVCO CORPORATION
AVCO SPACE SYSTEMS DIVISION
RESEARCH AND TECHNOLOGY LABORATORIES
Wilmington, Massachusetts

Final Report--AVSSD-0200-66-RR

Contract DA-19-020-AMC-0058(X)
DASA-WEB No. 07.007
Ordnance OMC Code: OCMS 5010.21.83036
DASA PO 311-62

by

H. Dolezalek
A. L. Oster

30 September 1966

Prepared for

COMMANDING GENERAL
HEADQUARTERS, ABERDEEN PROVING GROUNDS
Maryland

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UNCLASSIFIED ABSTRACT

As a continuation of Phase I of the final report, Phase II presents supplements for the theoretical considerations on the measurement of mobility spectra of atmospheric ions in the upper troposphere, stratosphere, and mesosphere. A preliminary evaluation of three free-air measurements in the height range from 5 to 40 km is discussed. The design of a new model (C) of the modified GERDIEN chamber for the height range from 40 to 80 km is described, applying the ac operation mode developed by the authors.

EDITED BY:
EDITORIAL SERVICES SECTION
R. ROTHENBERG

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PREFACE

The Phase I Final Report of this contract (DOLEZALEK and OSTER, 1965) extensively covers the theory of the measurement of ionic mobility spectra, and reports in detail the work done to realize the measuring idea by conducting laboratory experiments and preparing the first free-air measurements. The present report (Final Report Phase II) which is a continuation of work cited in TR-65-25, Phase I, covers the work performed from 5 September 1965 to 30 September 1966, and reports on the first free-air measurements and the preparation of others being planned. To facilitate the reading of the present Phase II report, it is written as a continuation of the Phase I report. Unless otherwise specified, the same symbols as listed in Phase I pp. xii through xv are used in the present report. Also, numbers of chapters (called "parts" in Phase I), equations, figures, and tables are continued. Parts I to III, equations (1) to (120), figures 1 to 55, and tables 1 to 7 are contained in Phase I.

A number of details on the free-air measurements and the development of the new instrument for further flights are contained in the monthly and quarterly reports submitted under this contract, and are not repeated here.

Some publications and reports on this project have already been printed, and several papers have been presented. These are, as listed in the reference section of Phase I: DOLEZALEK 1962, 1963; DOLEZALEK and OSTER 1963, 1964, 1965; and as listed in the reference section of this report: CORONITI, DOLEZALEK, and ISRAËL 1961, DOLEZALEK 1965, DOLEZALEK, OSTER, CORONITI, and MESTER 1966, OSTER and DOLEZALEK 1966, DOLEZALEK and OSTER 1966a, 1966b, 1966c.

ACKNOWLEDGEMENTS

We would like to express our gratitude to the persons listed in the "Acknowledgement" section of the Final Report Phase I; they have continued to help us during the period covered by the present report.

In addition, we want to express our sincere appreciation for a number of most valuable discussions on mobility and measuring methods with Professor J. Bricard of the Sorbonne (Paris), Professor L. B. Loeb of the University of California (Berkeley), Dr. V. Mohnen of the University of Munich (Germany), and Professor R. Siksna of the University of Uppsala (Sweden). In particular, we are indebted to Dr. H. W. Kasemir (now with the Environmental Sciences and Services Administration at Boulder, Colorado) for providing us with the results of his many experiments with electrometers with MOS-Field-Effect-Transistors, and for helpful discussions on measuring techniques.

Within the Avco Corporation, our acknowledgements now include Messrs. J. Shumsky, L. Pettingill, and H. Schlosser who, under the supervision of R. Schweiger, designed and constructed some essential electronic parts for the new model of the modified GERDIEN chamber.

PART 4

SUPPLEMENTS TO THE THEORY

4.1 MOBILITY AND DIFFUSION

Equation (8), on page 10 of Phase I, describes the EINSTEIN relation:

$$k = \frac{eD_{12}}{k_B T}$$

which is valid if the translational energies of the ion and the neutral molecules are equal. EINSTEIN, in his paper (1905), does not deal with "electrical" mobility at all, and a few words concerning the definition of the term "mobility" seem to be appropriate here. This term is, in fact defined in different ways. JUNGE (1963, p. 125) defines "mobility" as the velocity per unit driving force, and applies this definition to an aerosol particle moving in the atmosphere under the influence of gravitation:

$$k_g = \frac{v}{mg} . \tag{120}$$

The relation between this mobility and diffusion is

$$k_g = \frac{D'_{12}}{k_B T} , \tag{121}$$

and a combination of equations (120) and (121) leads to

$$D'_{12} = \frac{v k_B T}{mg} . \tag{122}$$

On the other hand, a combination of equation (8) and the usual definition of the "electrical" mobility as the velocity per unit field strength (i.e., per unit driving force divided by the electric charge) leads to

$$D_{12} = \frac{v k_B T}{eE} . \tag{123}$$

The essential difference in practical applications of equations (122) and (123) for the determination of the diffusion coefficient, D_{12} , is that (in atmospheric applications) the mass of the ion is generally not known, while the electric charge of the ion generally is known. The mass of the ion can vary practically continuously, while the electric charge, in the case of large ions, varies only in definite quanta.

4.2. THE PROBLEM OF THE CLUSTER IONS

In atmospheric electricity, figure 1 (Phase I) taken from WAIT's paper (1934) is often considered to be a valid expression for the formation of so-called cluster ions, i.e., clusters of a number of molecules (up to 12 or even 20 have been proposed) which carry, as a whole, just one electric charge. However, figure 1 shows a rather naive approach, based on calculations of the potential energy represented by the Coulomb forces around the ion, and the kinetic energy represented by the thermal motion of the molecules in the gas. This should lead to cluster ions which are termed by LOEB (1955, p. 48) as "labile clusters", and their mobility would be dependent on temperature as well as on field strength.

There is no doubt that this argument is valid. The kinetic energy is a function of temperature and of field strength, and in the frame of this theory the number of clustered molecules depends on the kinetic energy. It is a certain problem, however, if the changes occurring with variations of the kinetic energy are great enough to be detected by a mobility measurement. In the case of just a few neutral molecules clustered "around" an ion, this certainly is the case; it may be different if the number of clustered molecules is great.

In addition, there are a number of facts which indicate that clustering of many neutral molecules is highly improbable, and which make it probable that cluster ions do not exist in the lower atmosphere in appreciable numbers. In the higher atmosphere, their existence was doubtful from the beginning.

Unfortunately, the problem is not solved by these considerations. Measurements made by BRICARD (1965) and by SIKSNA (1966) lead to these conclusions:

1. Ions of theoretically the same mass can have different mobilities. In BRICARD's paper, there are two very distinct ranges of mobility for radon (Rn) ions, and three for toron (Tn) ions; in SIKSNA's analysis of BRICARD's data, Rn as well as Tn have five distinct mobilities each.

2. Ions of theoretically different masses can have the same mobility. BRICARD measured the mobility of radioactive ions, with Rn having 222 amu, and Tn having 220 amu. SIKSNA measures the mobility of air ions, having masses between about 14 and 32, and obtains the same mobilities as BRICARD.

Consequently, if the ions under consideration are atomar or molecular ions, mobility is determined not only by ion mass but by some additional factor which is obviously more important than mass. Or, if mass is the governing factor, the mass of the original ion could only be a fraction of the mass of the ion whose mobility has been measured, i.e., either complex ions or cluster ions have been formed. The formation of complex ions is a well known fact (e.g., N_4^+ in N_2 gas), but the existence of complex ions, e.g., N_9^+ (to match the masses of nitrogen and radioactive components), must still be shown.

This means that the measurement of the ion mobility spectrum, and its variations with height from the ground up to the mesosphere, is of even greater scientific interest than pointed out before. In particular, a combination of mobility measurements and direct mass determinations (by mass spectrometers) would be interesting in heights, where this can be achieved without pumping down the interior of the mass spectrometers.

4.3. THE ACCURATE MOBILITY SPECTRUM FORMULA

The equation for the mobility spectrum of a differential GERDIEN chamber of the second order, dc operation, plate condenser, is written as equation (67) (p. 30, Phase I). Substituting y_G for y_1, and x_E for x_1, it reads as

$$\frac{dn}{dk} = \frac{x_E b}{y_G} \frac{U}{e M_o M_G} I . \tag{67a}$$

This equation is a simplification for two reasons: it neglects the fact that the actual receiving electrode, located at distance x_E from the upstream end of the chamber, has a finite length, Δx; and the width of the ion gate, Δy, is considered negligible with respect to y_G. Without these simplifications, the current measured at one particular receiving electrode may be expressed, in generalized terms, as follows:

$$I_E = \Delta y e v b \left[\int_o^{k_{lf}} \frac{dn}{dk} f_o dk + \int_{k_{lf}}^{k_{lt}} \frac{dn}{dk} f_l \, dk + \int_{k_{lt}}^{k_{ut}} \frac{dn}{dk} f_t dk + \int_{k_{ut}}^{k_{uf}} \frac{dn}{dk} f_u \, dk + \int_{k_{uf}}^{\infty} \frac{dn}{dk} f_{\infty} dk \right] \tag{124}$$

In this equation, the k_{ij} are "critical" or "limiting" mobilities of incoming ions. Where $j = f$, a fractional interception of ions occurs at the receiving electrode under consideration, while for $j = t$, all ions are intercepted there. The index $i = l$ means a lower mobility limit, and $i = u$ means an upper mobility limit. These integration limits are listed in table 8. The coefficients f_m indicate the fraction of the ion numbers intercepted at the receiving electrode under consideration, and their values are listed in table 9.

These four limiting mobilites can also be briefly described as follows:

k_{lf}: lower limit of mobility for fractional interception at receiving electrode under consideration;
k_{lt}: lower limit of mobility for total interception at this electrode;
k_{ut}: upper limit for total interception;
k_{uf}: upper limit for fractional interception.

TABLE 8

LIMITING MOBILITIES OF THE DIFFERENTIAL GERDIEN CHAMBER OF THE SECOND ORDER, DC OPERATION, PLATE CONDENSER

Mobilities of ions which enter at the lower* edge of the ion gate and are intercepted at the downstream end of the receiving electrode under consideration:

$$k_{lf} = \frac{v}{E} \frac{y_G - \Delta y/2}{x_E + \Delta x/2} .$$

Mobilities of ion which enter at the upper* edge of the ion gate and are intercepted at the downstream end of the receiving electrode und.r consideration:

$$k_{lt} = \frac{v}{E} \frac{y_G + \Delta y/2}{x_E + \Delta x/2} .$$

Mobilities of ions which enter at the lower* edge of the ion gate and are intercepted at the upstream end of the receiving electrode under consideration:

$$k_{ut} = \frac{v}{E} \frac{y_G - \Delta y/2}{x_E - \Delta x/2} .$$

Mobilities of ions which enter at the upper* edge of the ion gate and are intercepted at the upstream end of the receiving electrode under consideration:

$$k_{uf} = \frac{v}{E} \frac{y_G + \Delta y/2}{{}_E - \Delta x/2} .$$

* the "lower edge of the ion gate" is the edge closer to the receiving electrode, while the "upper edge" is closer to the driving electrode (refer to figure 5).

TABLE 9

FRACTIONS FOR ION INTERCEPTION AT A PARTICULAR RECEIVING ELECTRODE OF THE DIFFERENTIAL GERDIEN CHAMBER OF THE SECOND ORDER, PLATE CONDENSER, DC MODE

Fraction of all ions with a mobility smaller than k_{lf} which are intercepted at the receiving electrode under consideration:

$$f_o = 0 .$$

Fraction of all ions with mobilities between k_{lf} and k_{lt} which are intercepted at this receiving electrode:

$$f_l = -\left(\frac{y_G}{\Delta y} - \frac{1}{2}\right) + \left(\frac{y_G}{\Delta y} - \frac{1}{2}\right)\frac{k}{k_{lf}} .$$

Fraction of all ions with a mobility between k_{lt} and k_{ut} which are intercepted at this receiving electrode:

$$f_t = 1 .$$

Fraction of all ions with mobilities between k_{ut} and k_{uf} which are intercepted at this receiving electrode:

$$f_u = +\left(\frac{y_G}{\Delta y} + \frac{1}{2}\right) - \left(\frac{y_G}{\Delta y} + \frac{1}{2}\right)\frac{k}{k_{uf}} .$$

Fraction of all ions with mobilities greater than k_{uf} which are intercepted at this receiving electrode:

$$f_\infty = 0 .$$

It may be mentioned that equation (124) is, in fact, a generalized form of equation (100) on p. 113 of ISRAËL (1957). Our equation (124), with the values given in tables 8 and 9, may also be written as follows:

$$I_E = \Delta y\, evb \left\{ \int_{k_{lf}}^{k_{lt}} \frac{dn}{dk}\left[-\left(\frac{y_G}{\Delta y} - \frac{1}{2}\right) + \frac{kE}{v}\frac{\Delta x}{\Delta y}\left(\frac{x_E}{\Delta x} + \frac{1}{2}\right)\right] dk + \int_{k_{lt}}^{k_{ut}} \frac{dn}{dk}\, dk + \int_{k_{ut}}^{k_{uf}} \frac{dn}{dk}\left[\left(\frac{y_G}{\Delta y} + \frac{1}{2}\right) + \frac{kE}{v}\frac{\Delta x}{\Delta y}\left(\frac{x_E}{\Delta x} - \frac{1}{2}\right)\right] dk \right\} \qquad (125)$$

Unfortunately, the further treatment of this equation is not only a mathematical problem, but depends also on the important physical problem of whether or not mobilities of atmospheric ions form a continuous or a line spectrum. This old problem is still in the stage of discussion. It is related to the cluster-ion problem discussed in the preceding section. Again, the existence of this problem calls for accurate measurements of ion mobility spectra in different altitudes.

4.4 ADDITION TO EQUATION (70) OF PHASE I REPORT

Equation (70) of the Phase I final report is written for the application of the outer electrode as driving electrode. If the inner electrode is used instead, it must be written in the following way:

$$k = \frac{R^2 - (y_G + r)^2}{x_E} \, v \, \frac{\ln R/r}{2U} \; . \tag{126}$$

PART 5

MEASUREMENT OF ION SPECTRA IN UPPER TROPOSPHERE AND STRATOSPHERE

5.1. INTRODUCTION

Ion mobilities have often been measured in laboratories (see LOEB, 1955). In the atmosphere, a number of measurements of mobilities of small ions, large ions, and charged aerosol particles has been carried out near the ground (see ISRAËL, 1957 and KNOLL, EICHMEIER and SCHÖN, 1964, pp. 198-205). Measurements of the ion mobility spectrum in the lower half of the troposphere have been reported by TSVANG and KOMAROV (1959) and by HOPPEL and KRAAKEVIK (1965). Measurements from higher atmospheric layers have been missing completely, and it is here that a number of important scientific problems do exist. As a first step to measure the ion spectra in the whole collision regime range (i.e., up to about 80 km of the terrestrial atmosphere), three measurements have been made in the lower half of that range: on 12 December 1965 up to about 31 km; on 6 January 1966 up to about 32 km; and on 10 January 1966 up to about 42 km altitude.

For these measurements, a modified GERDIEN chamber, Model B (as described in Phase I, pp. 137 to 164) has been carried aloft by high-altitude balloons of the National Center for Atmospheric Research, Balloon Flight Station, Palestine, Texas. The balloons were released at the indicated altitudes, and the actual measurements were made while the chamber was descending under a parachute at velocities below that of sound. The altitude, and hence, the falling velocity, was measured by a barocoder and a barograph. Altitude measurements have not been very accurate. In fact, they deviate from each other at some altitudes by several kilometers. The attitude of the instrument was monitored by two aspect magnetometers. Temperatures and important voltages were also monitored, and all data were transmitted to the ground station and recorded on magnetic tape and paper charts. The instrument was recovered after each flight, and reused.

A great number of mobility spectra has been recorded, but not all of them can be evaluated. In Flight No. 1, one electrometer failed; during Flight No. 2, oscillations obscure a few spectra; and in Flight No. 3, some spectra are not usable because the sero point of the electrometer shifted. Still, 17, 16, and 14 full cycles, each providing several positive and negative polar spectra, are available from Flight Nos. 1, 2, and 3, respectively.

The method applied was the differential GERDIEN chamber of the second order. The driving voltage was dc. According to p. 41 of Phase I, fourth paragraph, the dc method is inferior to the ac method because with it the wind velocity parameters must be known much more accurately for the evaluation of the spectrum. Since the methods to determine the actual falling velocity during the three flights have not been very reliable, we cannot expect that the results of this first attempt will be as accurate as they would be if the falling velocity had been measured with more reliable methods (e.g., radar or transponder).

5.2. THE PROBLEM OF THE AIR SPEED PARAMETERS

In the equation for the mobility spectrum (equation (67), p. 30, Phase I), two parameters are found, M_0 and M_G, which are both amounts of air passing through a certain cross section per unit time. In the case of M_G, this cross section is that of the ion gate; in the case of M_0, it is the cross section of the chamber itself. For a given instrument, M_G and M_0 are related to each other (and this relationship depends on atmospheric density and relative velocity between the instrument and the atmosphere).

Parameter M_G, or the air velocity through the ion gate, determines the number of ions entering the chamber per unit time. If we consider the ions within a certain mobility range, being intercepted at one particular receiving electrode, and being measured by the current I_E, the number density of these ions in the atmosphere is calculated according to

$$n_{(k,E)} = \frac{I_E}{e\,M_G} \qquad (127)$$

Parameter M_0, or the air velocity in the chamber itself, determines at which particular receiving electrode, E, ions with a certain mobility will be deposited by a certain electric field strength. For the case of the plate condenser we obtain

$$k_{(E)} = \frac{y_G\,M_0}{x_E\,E} , \qquad (128)$$

which is a greatly simplified equation but still shows the essential features. E is the electrical field strength, and y_G and x_E are the locations of ion gate and receiving electrode, as indicated in section 4.3.

The air velocity in equation (127) is in the denominator; in equation (128) it is in the numerator. This means that the assumption of too great a wind velocity would lead to too small an ion number density and/or too great a mobility.

Of the parameters M_G and M_0, both termed volumes of air passing per unit time through a given cross section, one, M_0, is in fact a rather complex magnitude. Parameter M_0 is a straightforward magnitude only when the wind velocity inside the GERDIEN chamber is the same at all locations, i.e., for the case of a completely flat wind profile throughout the whole chamber. In this case, we have the relation for the plate condenser

$$M_0 = v\,b\,d \qquad (129)$$

and for the cylindrical condenser

$$M_0 = v \pi (R^2 - r^2) \tag{130}$$

and the receiving electrodes for each mobility range are calculated in a very elementary way. However, this ideal case will never be the real case. There will be two complications: 1) the wind profile will not be flat, and 2) it will change along the chamber's axis; at the upstream end it will be rather flat due to the presence of the rings (not considering the dents made by the rings themselves), going downstream in the chamber the profile will become more and more quasi-parabolic, and near the downstream end it will flatten out again to a certain extent because of the aft rings. The actual forms of the wind profile cannot easily be predicted from aerodynamic theory; they should be measured in a special wind tunnel (see pp. 97 to 115, Phase I and OSTER and DOLEZALEK, 1966). The measurement must be done for every pair of air density and falling velocity encountered during the actual flight. The requirement leads to the necessity of post-flight calibrations; since, before the flight, it will not be known which falling velocity and corresponding air density will occur, it is practically impossible to calibrate these parameters before the flight. Once the post-flight calibration is done, the theoretical considerations reported on pp. 59 to 66 of Phase I may be applied, and the actual ion paths may be plotted.

For a first approach, two limiting cases have been studied: 1) the wind profile is a parabola throughout the chamber, and 2) the wind profile is flat throughout the chamber (both cases applied to a cylindrical condenser). The starting equations for case (1) are:

$$\dot{x} = \left(\frac{y_G - y}{a}\right)^{1/2} + v_o \tag{131}$$

$$\dot{y} = \frac{k\,U}{(R - y)\ln R/r} \tag{132}$$

which lead to the solution

$$\left.\begin{aligned} x = \ln R/r \; \frac{v_o}{k\,U y_G^{1/2}} \; & \left[- \frac{2R}{3} (y_G - y)^{3/2} + \frac{2}{15} (3y + 2y_G)(y_G - y)^{3/2} \right. \\ & \left. + R y\, y_G^{1/2} - \frac{1}{2}\, y^2\, y_G^{1/2} + C_1 \right] \end{aligned}\right\} \tag{133}$$

with y = distance between point under consideration and outer electrode, x = axial distance of point under consideration from intake, and C_1 = an integration constant which is easily determined by the conditions. The maximum velocity of the parabola is v_o.

For case (2) we start from the equations

$$\dot{x} = v_o \tag{134}$$

$$\dot{y} = \frac{k\,U}{(R - y)\ln R/r} \tag{135}$$

and obtain the solution

$$x = \ln R/r \; \frac{v_o}{k\,U} \left[Ry - \frac{y^2}{2} \right] + C_2 \qquad . \tag{136}$$

Here, C_2 is the integration constant which contains the parameter y_G .
A further simplification is made by assuming that the velocity in the ion gate is equal to v_o :

$$v_o = \frac{M_G}{\pi \left[\left(y_G + \frac{\Delta y}{2} \right)^2 - \left(y_G - \frac{\Delta y}{2} \right)^2 \right]} \qquad . \tag{137}$$

These equations may be applied to calculate preliminary ion spectra from the results of the flights, which will be the best available spectra for the period before the post-flight calibration is made. However, we are still uncertain about the value of v_o, since only v_f, the falling velocity of the instrument, is measured.

5.3 FALLING VELOCITY AND AIR VELOCITIES IN THE CHAMBER AND GATE

PALTRIDGE (1965) discusses the problem resulting from the fact that the velocity of the air flowing through the chamber is not necessarily the same as the velocity of the instrument falling through the atmosphere. In our case, the problem is even more complicated because of the air resistance created by the front and aft rings. Again, a solution can be obtained only experimentally, i.e., by a post-flight calibration, using a model of the instrument immersed in the air stream in the wind tunnel.

Some information on these relations may be obtained by varying certain parameters during several flights. For example, one can use the same instrument in two flights, keeping the cross section of the chamber itself constant, but applying two different apertures for the ion gate. Or, one can use the same instrument in two flights, and apply a funnel to the air intake opening for one of the flights. If one assumes that the real mobility spectrum is about the same at the same heights during the two flights, one may obtain information on the relations between v_f and v_o, and even on the relations between M_G and M_0 which may help in a preliminary evaluation.

5.4. PRELIMINARY EVALUATION OF BALLOON FLIGHTS

Applying equations (136) and (137), and assuming $v_o = v_f$, preliminary evaluations have been made.

For Flight No. 1, the aperture of the ion gate was increased. This has been done by taking out the second and the fourth rings at the upstream end of the chamber (see figure 53, p. 153 of Phase I, detail figure at the left hand margin, rings counted from inside out), so that only two rings remained, not including the inner and the outer electrodes. For Flight No. 2, the rings have been replaced, and a funnel was added at the air intake of the chamber. This funnel had a vertex angle of 60 degrees, and the forward opening had an area four times the opening area of the chamber itself. For Flight No. 3, this funnel was removed and the chamber was flown as shown in figure 53.

Two spectra of Flight No. 2, and on spectrum of Flight No. 3, were chosen for a first evaluation. The result is shown in figures 56, 57, and 58.

Figure 56 shows a preliminary ion mobility spectrum for positive ions, taken at a height of 7 km over Texas, on 6 January 1966. Data from only one driving voltage has been used, i.e., the evaluation was done only according to the mode of the differential chamber of the second order. Wind velocity in the ion gate and in the chamber itself are assumed to be equal to the falling velocity, obtained by averaging the measurements of the barocoder. Thus, the action of the funnel was neglected.

Figure 57 shows a preliminary mobility spectrum of negative ions, obtained at about 22 km over Texas on the same day. Both modes of evaluation (differential chambers of the first and second orders) have been used, i.e., spectra from several driving voltages have been superimposed, leading to a better resolution. Air speed in the ion gate and in the chamber itself was assumed to be four times as great as the falling velocity, i.e., the action of the funnel was considered fully.

Figure 58 shows a preliminary mobility spectrum of negative ions, obtained at about 37 km over western Louisiana on 10 January 1966. Only data from one driving voltage were used, and no attempt was made to improve the resolution, since the velocity data are particularly inaccurate in this case. Air speeds in the ion gate and in the chamber were assumed to be equal to the falling velocity. No funnel was attached to the instrument.

In figures 56 through 58, an arrow close to the abscissa indicates the theoretical average ion mobility, taken from table 202 on p. 76 of Phase I. A round dot close to the upper margin shows the average mobility calculated from the measured ion spectrum.

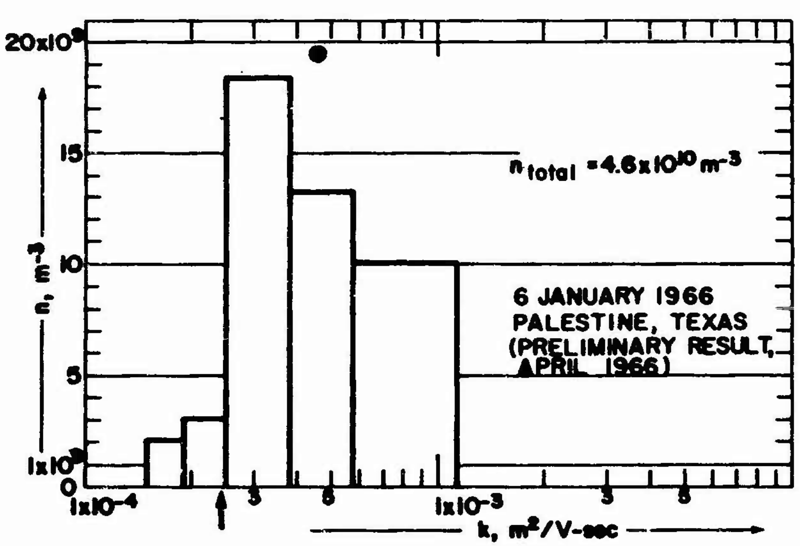

Figure 56 PRELIMINARY ION MOBILITY SPECTRUM; POSITIVE IONS, 7 KM

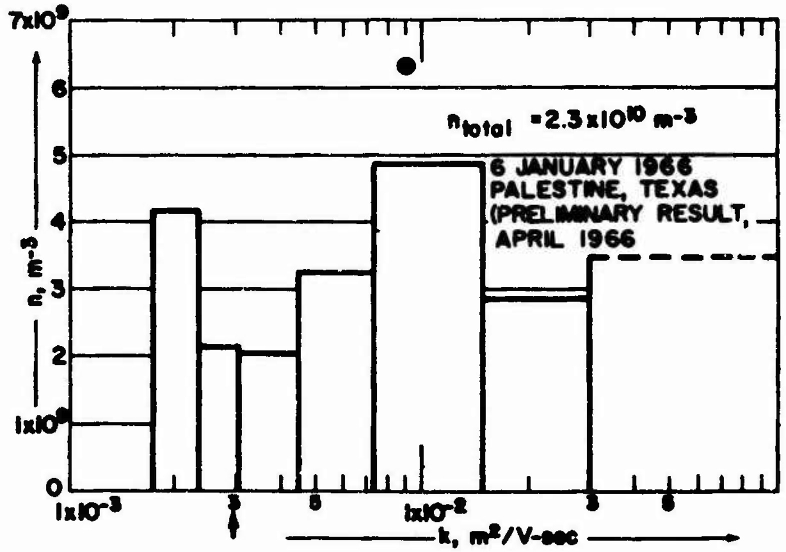

Figure 57 PRELIMINARY ION MOBILITY SPECTRUM; NEGATIVE IONS, 22 KM

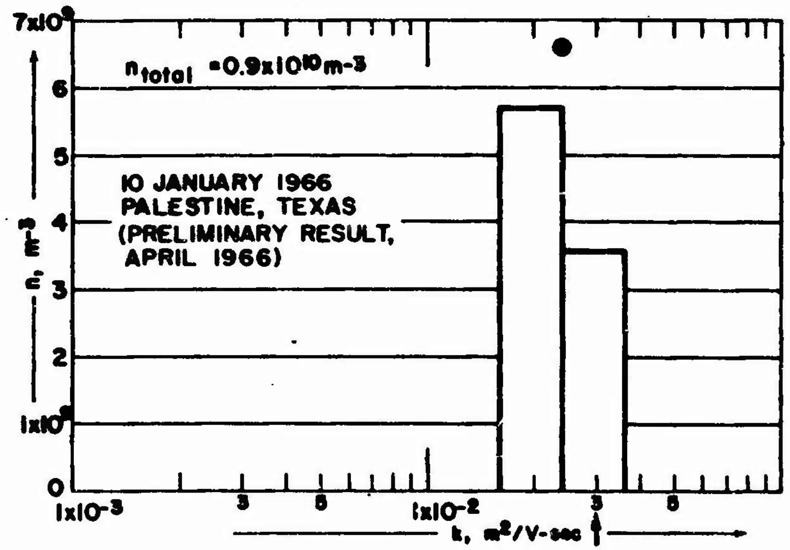

Figure 58 PRELIMINARY ION MOBILITY SPECTRUM; NEGATIVE IONS, 37 KM

86-8100

5.5 DISCUSSION OF PRELIMINARY ION SPECTRA

At first, we compare our preliminary results with theoretical values or with the results of other researchers. Since mobility spectra have neither been measured before in these regions nor calculated on a theoretical basis, we can only compare total ion number densities with the measurements of total ion number densities made by other researchers, and we can compare average mobilities with theoretically predicted values. However, these two discussions are related, since the wind speed in the ion gate and the wind speeds in the chamber are interrelated (see section 5.2, first paragraph).

The total ion number densities, calculated as the sum of the individual ion number densities per mobility range in figures 56, 57, and 58, are entered in table 10, and roughly compared with the results of WHIPPLE (1965, p. 136).

TABLE 10

TOTAL ION NUMBER DENSITIES IN THE STRATOSPHERE

According to WHIPPLE			According to our Preliminary Results*			Ratio
Height (km)	Polarity	Density (m^{-3})	Height (km)	Polarity	Density (m^{-3})	
10	positive	1.1×10^{10}	7	positive	4.6×10^{10}	4.2
22	negative	1.1×10^{10}	22	negative	2.3×10^{10}	2.1
37	negative	2.0×10^{9}	37	negative	9.0×10^{9}	4.5

* Under the assumptions explained in the text

As mentioned above, for our 22 km measurements the action of the funnel has been considered by multiplying the wind speed by four. According to equation (127), a multiplication of the wind speed by two instead of four would give an ion number density of 4.6×10^{10}, and change the ratio of table 10 to 4.2, i.e., about equal to the ratios at the other heights. However, the funnel was present for the 7 km measurement as well, but its action at this height may be very different from those at 22 km. The Reynold's numbers for the flights at 22 and 7 km may differ by a factor of 30. Thus, the funnel action also differs, but we cannot say how much.

If, instead of WHIPPLE's figure, we take the results of BRAGIN (1965, first launch), we obtain ratios of 35 at 7 km, 2.9 at 22 km, and values between 180 and 1.3 at 37 km. The strong deviation at 37 km is caused by a sharp decrease

of ion density in BRAGIN's numbers at 36 to 38 km. The discrepancy between BRAGIN's and WHIPPLE's figures as well as the low reliability of our velocity measurement at 37 km prevents the drawing of any further conclusions from these comparisons.

Average mobilities, compared with the theoretical values of table 202 on p. 76 of Phase I, are entered in table 11.

TABLE 11

AVERAGE ION MOBILITIES IN THE STRATOSPHERE

Theretical Value		Weighted Average of Our Preliminary Results*		Ratio
Height (km)	Average Mobility (m^2/ V-sec)	Height (km)	Average Mobility (m^2/ V-sec)	
7	2.4×10^{-4}	7	4.4×10^{-4}	1.8
22	3.0×10^{-3}	22	9.0×10^{-3}	3.0
37	3×10^{-2}	37	2.3×10^{-2}	0.8

* Under the assumptions explained in the text

Again, reducing the action of the funnel to two (instead of four) results in an average mobility of 4.5×10^{-3} for the height of 22 km; the ratio would then be 1.5, better matching the other ratios.

These preliminary results, taking each group separately, do not seem to deviate too much from the values measured by other authors or from the theoretical values. This statement no longer holds if we take the preliminary results together, making the simple assumption that the wind speed in the ion gate was equal to the wind speed in the chamber. If we try to match the values of the total ion number densities by changing the ratios of table 10 to 1, we must decrease the wind speed in the ion gate; but in order to match the average mobilities, we should increase the wind speed in the chamber. On the basis of the equality of the two wind speeds, the matched ratios of either the number densities or the mobilities, the ratios of the other parameter would increase to about 9, or almost a full order of magnitude. This fact very clearly shows the necessity of the post-flight calibration.

In addition, it must be mentioned that even the shape of the mobility curves, as presented in figures 56, 57, and 58, may change as a result of the post-flight calibrations; if the wind profile varies significantly along the axis of the

chamber, the dispersion of mobilities along the receiving electrode varies also, and the maxima and minima of the curves may be shifted. Even their number may change.

In conclusion, the preliminary results clearly show the feasibility of the method. Results with a good resolution have been obtained; many more results of the same character can be derived from the recorder charts. There is no reason to doubt that the post-flight calibrations will solve the evaluation problems outlined in this section. There is also no doubt that these post-flight calibrations are necessary, and that the best possible methods of measuring the falling velocities of dc-operated GERDIEN chambers should be applied in future experiments.

PART 6

DESIGN OF MODIFIED GERDIEN CHAMBER, MODEL C

6.1. INTRODUCTION

As stated on p. 139 of Phase I, second paragraph, Model B of the modified GERDIEN chamber has been designed to be used for experiments in the lower half of the total height range (40 to 5 km dc operation, balloon launching) as well as in the upper half (80 to 40 km, ac operation, rocket launching). Model B has been built in such a way that by changing some electronic parts, and by replacing the front rings by another set, the instrument would be adapted to the upper half of the height range. For the balloon launching, the requirements with respect to vibration and shock strength were negligible, but for the intended rocket launch and parachute ejection, rather demanding requirements had to be met (e.g., 300 g acceleration).

However, after the Model B had been built, further investigations into the possibilities for launching and parachuting have shown that a) the acceleration of 300 g would not occur, b) the Model B was too heavy for the parachute, and c) the overall diameter and length should be changed as well. Furthermore it seemed desirable to use the instrument for measurements during the solar eclipse of November 1966. Three or four modified GERDIEN chambers were to be launched for measurements prior, during, and after totality of the eclipse, and from about 75 km down to about 35 km. Consequently, a new instrument, Model C, had to be designed, which would be lighter, and shorter, and which would give a higher resolution of the data.

The design of this new instrument was 95 percent complete when lack of funds prevented any additional work; at that time, the actual construction was 75 percent complete (this refers to the first instrument, C-1). The design of this Model C is described in the following section.

6.2. GENERAL DESCRIPTION OF MODEL C MODIFIED GERDIEN CHAMBER

To obtain maximum strength with minimum weight, the chamber consists essentially of two coaxial cylinders, between which a three-sided prism is situated. The three planes of the prism serve as mounting platforms for electronics and batteries (in three groups: 1) electrometer amplifiers 2) batteries and electronic supply and 3) commutator and transmitter). The inner cylinder consists of the 15 receiving electrodes (outer electrodes of the GERDIEN chamber proper), mounted with extremely high insulation to the three plates of the prism. The outer cylinder is the skin of the instrument. The inner electrode of the chamber (the "driving electrode") is a rod in the axis of the chamber, again consisting of 45 insulated individual electrodes, permitting the increase of the driving voltage amplitude along the axis (refer to pp. 33 through 34 of Phase I). Figure 59 is a sketch of the new chamber.

The configuration of the front rings has been changed. As seen from Figure 60, it is more complicated now. This was necessary a) to increase the resolution, and b) to shorten the actual length of the ion gate, thus allowing for short opening times of the gate (refer to p. 38, figure 9, and pp. 56-58 of Phase I).

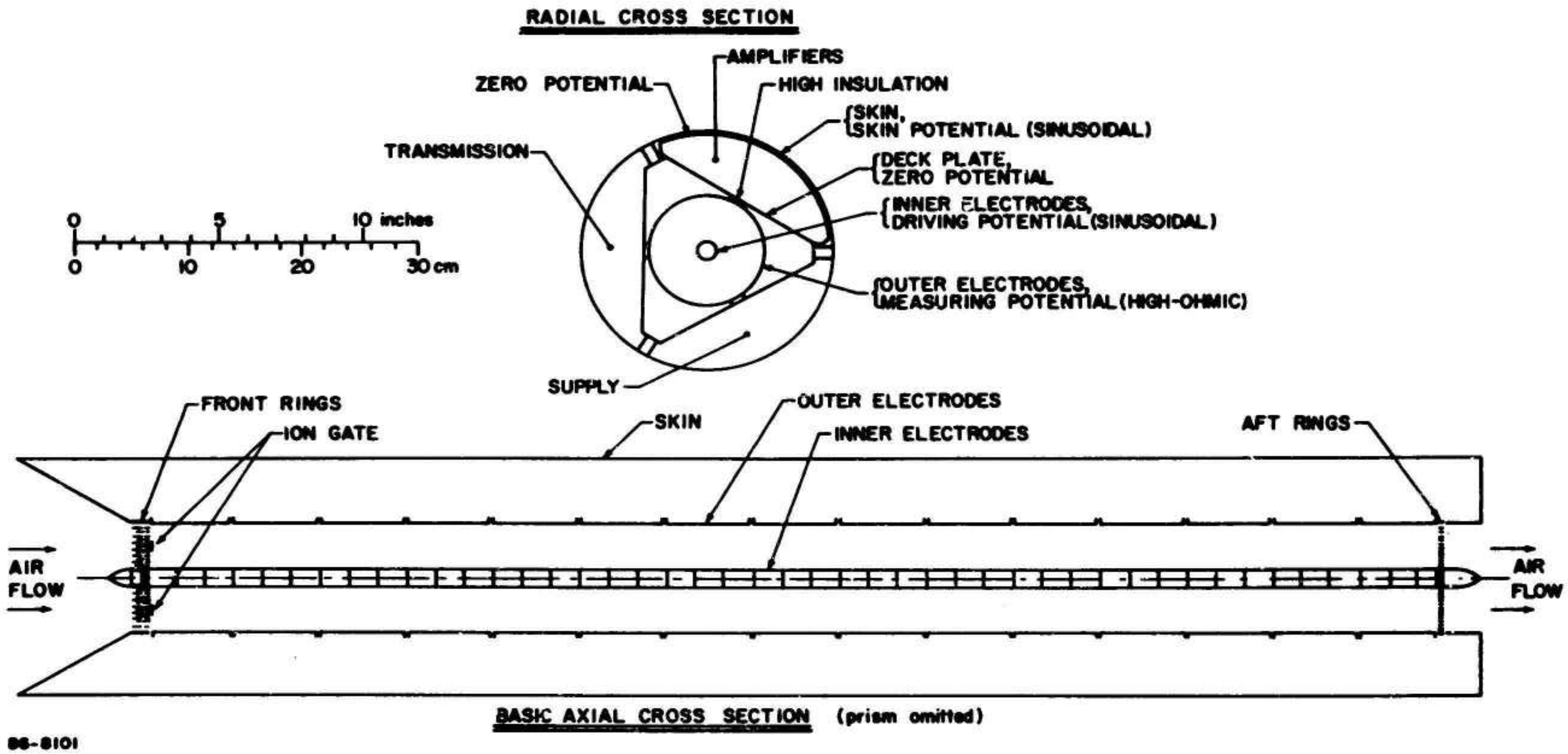

Figure 59 SKETCH OF MODIFIED GERDIEN CHAMBER, MODEL C

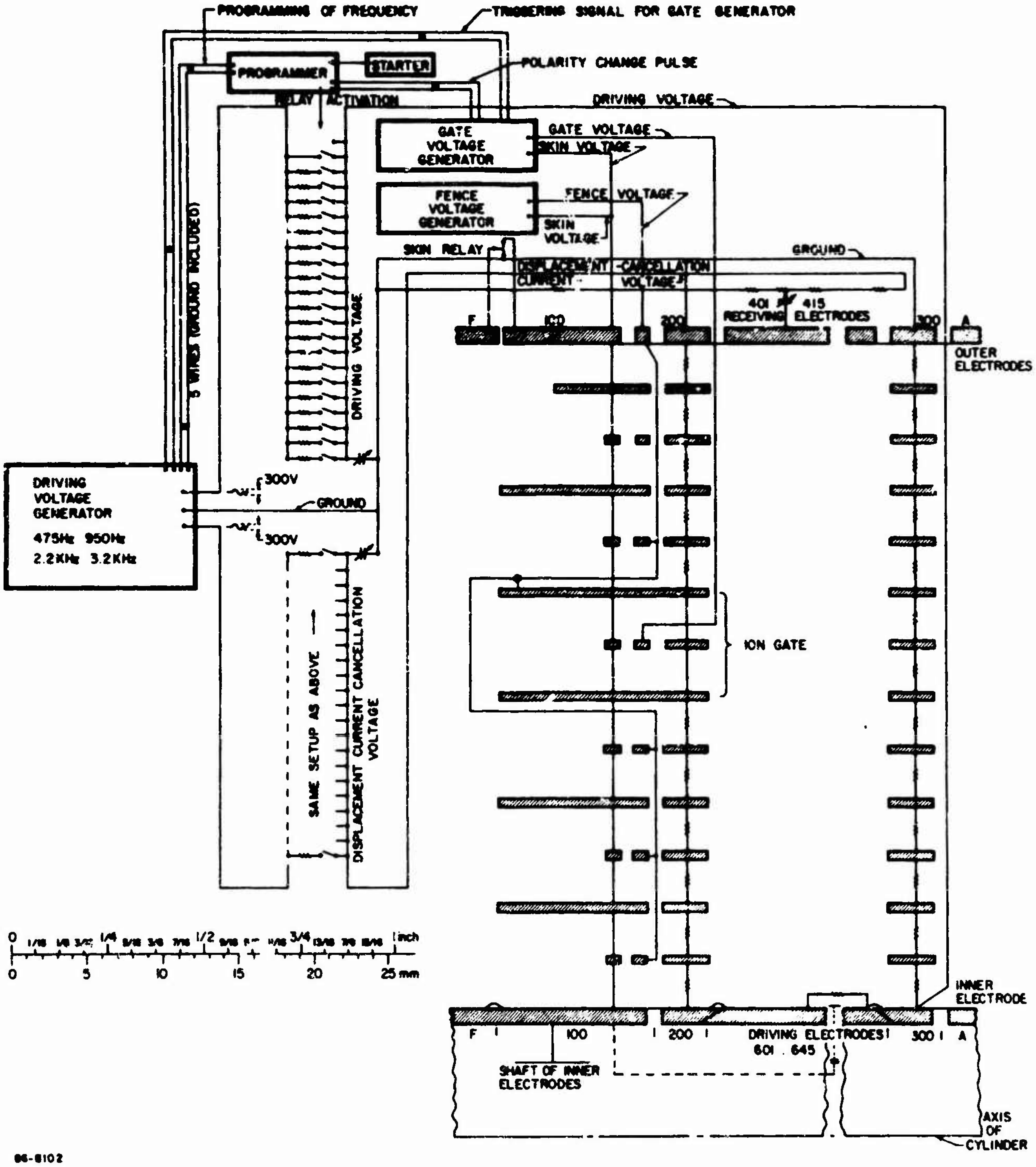

Figure 60 SKETCH OF RING CONFIGURATION FOR MODEL C

6.3. PARAMETERS FOR THE OPERATION OF MODEL C

While the instrument is descending under the parachute, the air density, (and with it the average mobility) and the falling velocity vary. Also, the function of all wind parameters in the chamber versus falling speed will change, and the nature of ions may vary as well, leading to another type of mobility variation. Considering these many variations, the control of driving voltage parameters such as frequency, voltage, and possibly voltage ratio along the axis, would best be accomplished by observing the output of the electrometer amplifiers. If these outputs indicate, for example, that the main impact area of ions moves toward the rear end of the chamber, the driving voltage should be increased, or the frequency decreased. Such "programming by the output" would require some kind of a computer to be flown with the instrument. This method certainly is the most reliable one. However, for the time being it was decided to select the simpler way of "programming by time": a programmer is set by some impulse connected to the launching time, and on the basis of calculations and prior experiments with dummy models, the driving voltage parameters are switched by a time-controlled unit.

In order to measure positive as well as negative ions, the phase of the ion gate is also shifted with every switching process (see p. 38, figure 9, of Phase I, lower left).

The selected values of the driving voltage and frequency are shown in table 12 (for more details, refer to Quarterly Progress Report No. 10 of this contract).

The parameters for the operation of the ion gate have been calculated under consideration of the expected falling speed, which, in a first approximation, was assumed to be equal to the wind speed in the ion gate. Due to the finite time required for an ion to pass the rings after the ion gate has been opened, and the finite time required for an ion to pass the last rings after the ion gate has been closed, the opening and closing times of the ion gate do not quite coincide with the crossing of the zero-line of the driving voltage. For an effective ion gate length of 3mm, and an effective length of the last set of front rings of also 3mm, the ion gate parameters have been calculated as shown in table 13A. Here, the phase τ_{op} is the time, in microseconds, between the "electrical" opening of the ion gate and the arrival of the first ion in the chamber; phase τ_{cl} is the time between the "electrical" closing of the ion gate and the arrival of the last ion in the chamber proper. All times are counted from the zero crossing point of the driving voltage. In terms of phase angles, the ion gate operates as shown in table 13B.

TABLE 12

ZERO-TO-PEAK VOLTAGE AND ANGULAR FREQUENCY OF DRIVING VOLTAGE

Step No. of Program and Polarity of Ions to be Measured	Time Interval Between 80 km Altitude and Switching (seconds)	Time Interval Between 80 km Altitude and Measurement Set (seconds)	Approximate Height (km)	U/ω Values (volts)		Frequency (sec^{-1})	Zero-to-peak Driving Voltages (U) for Electrodes of GERDIEN (volts)	
				Last Electrode	First Electrode		Last Electrode	First Electrode
1, -	--	0	78	1.5×10^{-4}	1.8×10^{-5}	20×10^3	3.0	0.36
2, +	15	30	75	4.7×10^{-4}	6.0×10^{-5}	20×10^3	9.4	1.2
3, -	45	60	70	1.0×10^{-3}	1.3×10^{-4}	20×10^3	20	2.6
4, +	75	90	66	1.3×10^{-3}	2.3×10^{-4}	14×10^3	18.2	3.2
5, -	105	120	62	3.0×10^{-3}	3.2×10^{-4}	14×10^3	42	4.5
6, +	135	150	59.5	4.2×10^{-3}	3.8×10^{-4}	14×10^3	59	6.7
7, -	165	180	57	5.5×10^{-3}	6.0×10^{-4}	14×10^3	77	8.4
8, +	195	210	55	6.8×10^{-3}	7.9×10^{-4}	6×10^3	40	4.7
9, -	225	240	53	9.0×10^{-3}	1.0×10^{-3}	6×10^3	54	6.0
10, +	255	270	51.5	1.1×10^{-2}	1.2×10^{-3}	6×10^3	66	7.2
11, -	285	300	50	1.3×10^{-2}	1.5×10^{-3}	6×10^3	78	9.6
12, +	315	330	48.5	1.5×10^{-2}	1.7×10^{-3}	6×10^3	90	10.2
13, -	345	360	47	1.8×10^{-2}	2.0×10^{-3}	6×10^3	108	12.0
14, +	375	390	46	2.1×10^{-2}	2.4×10^{-3}	6×10^3	126	14.4
15, -	405	420	45	2.4×10^{-2}	2.8×10^{-3}	6×10^3	143	16.8
16, +	435	450	44	2.7×10^{-2}	3.2×10^{-3}	3×10^3	81	9.6
17, -	465	480	43	3.1×10^{-2}	3.5×10^{-3}	3×10^3	93	10.5
18, +	495	510	42	3.6×10^{-2}	4.0×10^{-3}	3×10^3	108	12.0
19, -	525	540	41	4.0×10^{-2}	4.4×10^{-3}	3×10^3	120	13.2
20, +	555	570	40.3	4.5×10^{-2}	5.0×10^{-3}	3×10^3	135	15.0
21, -	585	600	39.5	5.0×10^{-2}	5.5×10^{-3}	3×10^3	150	16.5

TABLE 13A

ACTUAL ION GATE TIMES FOR FIXED PHASE ANGLES OF -41 AND 57 DEGREES

($l_1 = l_2 = 3$ mm)

Step No. According to Table No. 12	Height of Measure-ment (km)	Falling Velocity (m/sec)	Phase τ_{op} Lasts from .....to...... (microseconds*)	Electric Opening τ_{cl} Lasts from..........to... if Fixed to 57° (microseconds*)	Phase τ_{cl} Lasts from..........to...... if τ and τ_{op} are Fixed as Indicated (microseconds*)	Effective Opening Time τ_{eff} Lasts from..........to........ Under These Conditions (microseconds*)
1	78	180	-29.5...+3.5	-29.5...+19.9	+19.9...+34	+3.5...+34
2	75	228	-29.5...-3.1	-29.5...+19.9	+19.9...+24	-3.1...+24
3	70	188	-29.5...+2.5	-29.5...+19.9	+19.9...+31	+2.5...+31
4	66	140	-58.0...-15.0	-58.0...+14.5	+14.5...+36	-15.0...+36
5	62	102	-58.0...+ 1.0	-58.0...+14.5	+14.5...+44	+ 1.0...+44
6	59.5	87	-58.0...+11.0	-58.0...+14.5	+14.5...+49	+11.0...+49
7	57	77	-58.0...+16.0	-58.0...+14.5	+14.5...+54	+16.0...+54
8	55	70	-120...-34	-120...+45	+45...+88	-34...+88
9	53	63	-120...-25	-120...+45	+45...+91	-25...+91
10	51.5	58	-120...-16	-120...+45	+45...+103	-16...+103
11	50	53	-120...-7	-120...+45	+45...+108	- 7...+108
12	48.5	48	-120...+5	-120...+45	+45...+113	5...+113
13	47	44	-120...+15	-120...+45	+45...+123	15...+123
14	46	40	-120...+30	-120...+45	+45...+128	30...+128
15	45	37	-120...+41	-120...+45	+45...+135	41...+135
16	44	35	-188...-18	-188...+32	+32...+242	-18...+242
17	43	32	-188...- 2	-188...+32	+32...+240	- 2...+240
18	42	31	-188...+ 5	-188...+32	+32...+243	+ 5...+243
19	41	30	-188...+12	-188...+32	+32...+246	+12...+246
20	40.3	28	-188...+27	-188...+32	+32...+254	+27...+254
21	39.5	27	-188...+34	-188...+32	+32...+257	+34...+257

*Counted from the zero crossing point of driving voltage.

TABLE 13B

PHASE ANGLES FOR ION GATE OPERATION

The phase angle of the "electrical" opening time of the ion gate has a duration of 57 degrees and goes:

From (degrees)	To (degrees)	For Programmer Step Nos.
-35.23	21.77	1 to 3
-45.80	11.20	4 to 7
-41.00	16.00	8 to 15
-32.13	24.87	16 to 21

6.4. BRIEF DESCRIPTION OF THE ELECTRONICS OF MODEL C

The following units of the electronics system have been under preparation by Avco:

a. Electrometer amplifiers for the amplification of the signal from the receiving electrodes;

b. Cancellation line for the main displacement current, also connected to the receiving electrodes;

c. Generator for driving voltage, voltage for cancellation of displacement current, and the ion gate pulses, the so-called AC Supply Package.

d. Voltage divider to adjust these voltages to the one listed in table 12;

e. Ion fence voltage supply for the ion fence or ion filter;

f. Skin-relay for adjusting the potential of the outer skin of the instrument for the measuring period;

g. Starter for the provision of the starting signal for the program;

h. Programmer to control the voltages, frequencies, and polarities according to table 12.

These units are briefly described in the following paragraphs.

The electrometer amplifier is a feedback electrometer with a differential operational amplifier as a second stage. The feedback bridges the two stages at once. Instead of an electrometer tube, a MOS-field-effect transistor has been used and the whole circuit has been miniturized. Also, since the displacement currents are cancelled by other means than in Model B (see below), no switch is in the electrometer, and the receiving electrode is directly connected to the gate ("grid") of the transistor. The application of transistors instead of tubes eliminates the need for power to heat the filaments. It is true that the MOS-field-effect transistors are difficult to handle and, similar to electrometer tubes, must be biased individually after the characteristics of each individual transistor have been investigated. However, according to the long experience of Dr. H. W. Kasemir with these transistors, and after conducting a number of experiments with Dr. Kasemir, it was decided that the procedure is feasible and can be applied. During these experiments, the electrical signals to be expected at the receiving electrode have been simulated. It turned out that this electrometer also has sufficient integration capability to overcome the difficulties caused by the displacement currents from the passing ions (refer to pp. 41 to 48 of Phase I). Figure 61 shows the schematic of this electrometer amplifier.

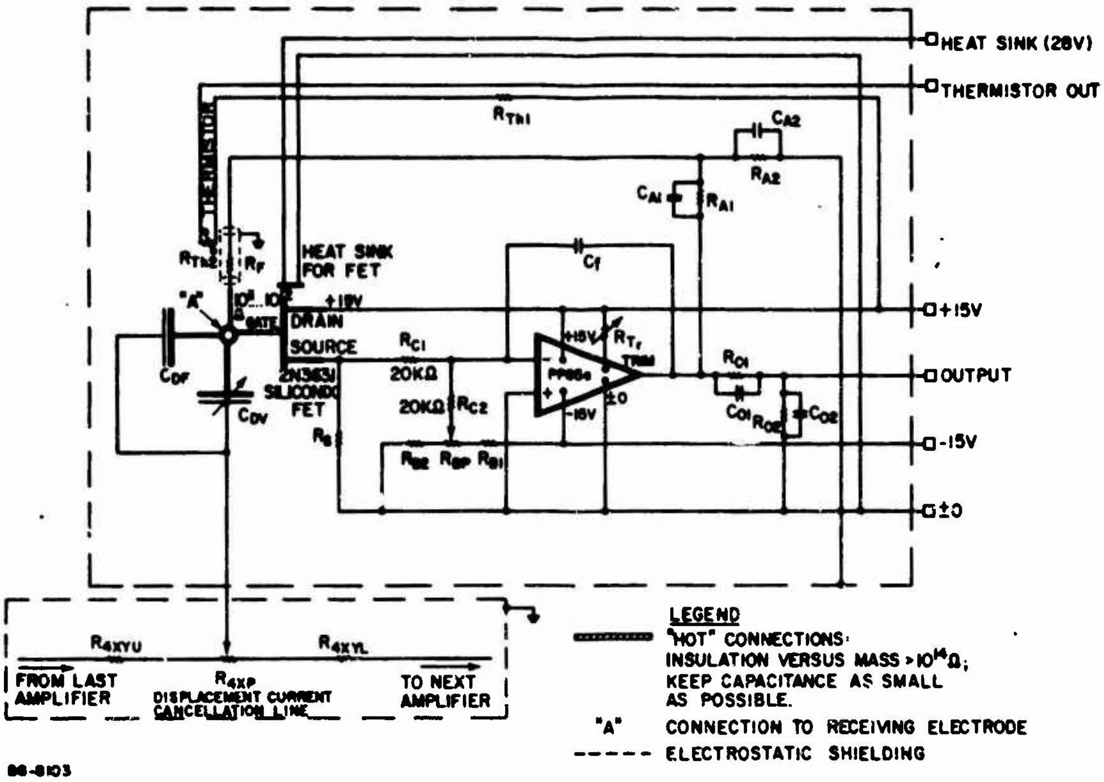

Figure 61 SCHEMATIC OF ELECTROMETER-AMPLIFIER FOR MODEL C

The cancellation of the main displacement current (caused by the application of an ac voltage to the driving electrode) will be made by applying voltages (with the same frequency, but the phase shifted by exactly 180 degrees), via a highly insulated capacitor, to the receiving electrodes. This capacitor balances the capacitance between driving electrode and receiving electrode in the chamber. Care must be taken to avoid any additional phase shifts. This is done by applying exactly the same values for resistance and stray capacitances, for the driving voltage lines and for the displacement current cancellation lines. The finite cancellation will be accomplished by fine potentiometers built directly into the electrometer.

Generation of the driving voltage, the voltage for the cancellation of the displacement current, and the ion gate pulses is done by a combined component, the "ac supply package". A block diagram of this component is shown in figure 62. The operation is as follows (numbers in parentheses refer to components shown in figure 62):

> A phase shift oscillator (1) generates four sinusoidal voltage variations, which can be selected by one of four inputs controlled by the programmer (activating at steps No. 1, 4, 8, and 16; see table 12). The oscillator feeds a buffer amplifier (2), which provides the necessary gain to operate the driver and final high voltage amplifier (3). Feedback is employed between the final amplifier and the buffer amplifier to minimize distortions inherent in the Class B stage of the final amplifier. The output transformer (4) steps the voltage up to 300 volts peak-to-peak, thus providing the voltages for the driving electrodes and for the displacement current cancellation line. A portion of the output voltage is returned to the oscillator (1) where it is detected and used to provide automatic gain control. This produces a stable output with reasonable line and load fluctuations. The zero-crossing detector (5) samples the output voltage and develops a square wave which changes state when the output voltage passes through zero. The square wave output from the zero-crossing detector (5) triggers the delay generator (6). This delay generator develops a pulse that has a programmed phase relationship to the 300-volt output. These phase delays are the ones which are called τ_{op} and τ_{cl} in table 13A, and they are again controlled from the programmer. The delay times developed in the delay generator have a certain relation to the frequency of the transformer output (4). The pulse from the delay generator then drives the gate generator (7), which in turn produces a pulse of a programmed period to drive the gate circuits (8). The gate circuits provide an insulated 50 volts between the rings constituting the ion gate in the front rings system of the GERDIEN chamber (see figure 60). They also provide a zero voltage between these gate rings for the periods, τ, in which the ion gate is open. A gate disable line (9) is incorporated to facilitate ground testing of the unit. The frequency monitoring circuits (10) develop a voltage which is proportional to the

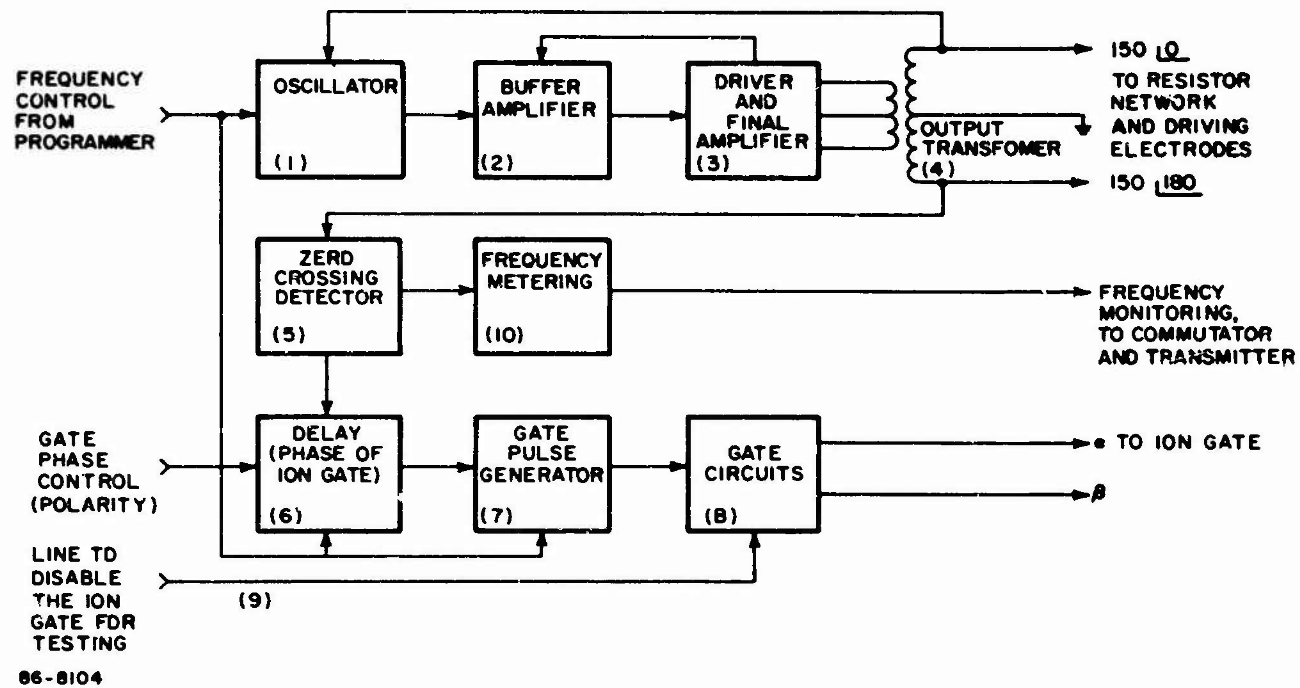

Figure 62 BLOCK DIAGRAM OF "AC SUPPLY PACKAGE" FOR MODEL C

frequency of the square wave input, and thus of the driving voltage output of transformer (4). This voltage is supplied for the purpose of monitoring the frequency. The driving voltage is monitored by the provision of a fixed portion of the transformer output. Both monitoring voltages are to be fed into the commutator and transmitted from the instrument to the ground station during the flight.

The voltage division for the driving voltage and the voltage for the displacement current cancellation line is accomplished by two banks of 22 resistors each (see figure 60), connected and disconnected by relays which in turn are activated from the programmer for each of the steps of table 12.

The ion fence voltage, i.e., the voltage which prohibits ions from passing through the front rings (except for the ion gate), is provided by a small power supply (voltage transducer).

A so-called "skin-relay" connects the outer skin of the instrument to the voltage of the first set of rings when the instrument is ejected from the rocket. While in the rocket, the skin must be on rocket potential.

The starter is a combination of relays providing the starting signal for the programmer at a certain, adjustable time after the starter has received a signal generated by the ejection of the nose cone of the rocket.

The programmer, driven by a small motor via a gear work, consists essentially of a number of fine brushes gliding on a rotating disk. On the disk, parts of printed circuit lines provide the contacts for the brushes.

6.5. ADDITIONAL ELECTRONIC UNITS

All electronic units described in the preceding section are powered by 28-volt batteries, with negative poles grounded to the instrument. Space for these batteries is provided in the instrument itself. The same is true for the commutator and transmitter. The antennas for the transmitters, and additional antennas for a range finder system (transponder), are located on the outer skin of the instrument.

A number of additional electronic components have been designed for testing of the individual parts of the system. These include a program simulator and a signal simulator. The latter simulates the signal as it is expected to be provided by the ions intercepting at the receiving electrode; the peaks of a sinusoidal curve are cut off and brought down to the zero line. It also provides a full sinusoidal voltage in two phases, differing by 180 degrees, for the testing of the displacement current cancellation (all three outputs being in the correct phase).

Provisions for monitoring important supply voltages and frequencies, for measuring temperatures, and for the installation of aspect sensors, are also made.

These components are described in detail in the monthly and quarterly reports under this contract, and are not repeated here.

PART 7

SUMMARY

SUMMARY

In the collision regimes of the atmospheres, mobility is an important parameter for the description of the ionic state. It is defined as the average drifting velocity of the ions under the influence of an electric field of unit strength. If ions of different mobilities are present, the proper presentation of the general ionic state is the mobility spectrum, or the number density of ions per mobility range. In principle, the mobility spectrum can be measured directly. The relations between the mobility spectrum and other parameters of the ionic state in the atmosphere are not fully understood in all cases, and much research is required to obtain more accurate and reliable quantities for the calculation of one parameter from another. The measurement of the mobility spectra is one part of such research. In addition, such measurements can already be used with a certain degree of accuracy and reliability to derive other parameters, based on the present state of the art.

Mobility spectra of atmospheric ions have been measured close to the ground and in the terrestrial troposphere up to about 5 km, in the period between 1905 and 1964. This report covers a project to extend such measurements throughout the whole troposphere, stratosphere, and mesosphere. For the lower half of the collision regime (on Earth up to about 40 km), well-known measuring techniques may be adapted and used, while for the upper half (on Earth up to almost 80 km), a new technique had to be invented. This was necessary for two reasons: 1) The well-known techniques require rather accurate information on the wind velocity in the measuring chambers, and 2) the resolution of these techniques depends on the inversed square of the average mobility, i.e., it decreases drastically in higher altitudes. The new technique was proposed by DOLEZALEK in 1962. It avoids both of the shortcomings of the older methods. Any measurement of ionic mobility consists of the measurement of a length travelled by the ion in a certain time under the influence of a known field. In the classical methods, as developed and used in the domain of atmospheric electricity, this length is measured by applying the air velocity as a second parameter, the vector of which is directed perpendicularly to the direction of the field. The air carries the ions downstream for a certain time with a known velocity, and thus measures a length. This time depends on mobility, field strength, and the geometrical dimensions of the chamber. In the new method, a variation of the direction of the electric field is used instead. By the application of a sinusoidal driving voltage in the chamber, the amplitude of which increases along the chamber's axis, the time intervals are well known and the length intervals are given by the mobility to be measured, the amplitude of the sinusoidal field, and the geometric dimensions of the chamber. Ions enter the chamber at a predetermined radius and a predetermined phase during only a small fraction of the period of the driving voltage. The internal and external fields are equalized, and the edge effect is reduced.

The feasibility of the new method has been proven in the laboratory, using a special low-density wind tunnel. Some test flights using a modification of the perpendicular velocities method have been conducted using high-altitude balloons and parachutes. They provide the first ion mobility spectra in the 5- to 40-km height range. A preliminary evaluation of these measurements has been accomplished and the final evaluation has been prepared. For the 40- to 80-km range, two different instruments have been developed and partially built, but no flight has been made so far. It is hoped that measurements of the ion mobility spectra in the full height range from ground to the mesopause will be made with these instruments in the future.

From such flights, a number of old and new problems of ion physics hopefully can be solved or at least approached: the old problem of cluster and complex ions in different heights; the problem of aerosol particles (especially in the height ranges between 15 and 25 km and between 50 and 60 km); the mass and chemical nature of the ions; information on recombination coefficients and ionic mean free paths; knowledge about the atmospheric electric conductivities, the columnar resistance and thus the atmospheric electric global circuit; and indications on penetrating ionizing radiation from above. These are just a few of the scientific problems involved. Of course, the same methods can be applied for measurements of this type in atmospheres other than the terrestrial one.

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As a continuation of Phase I of the final report, Phase II presents supplements for the theoretical considerations on the measurement of mobility spectra of atmospheric ions in the upper troposphere, stratosphere, and mesosphere. A preliminary evaluation of three free-air measurements in the height range from 5 to 40 km is discussed. The design of a new model (C) of the modified GERDIEN chamber for the height range from 40 to 80 km is described, applying the ac operation mode developed by the authors.

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